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Detecting Deterioration In Asphalt-Covered Bridge Decks

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Abstract

Information on the condition of bridge decks is required for reasons of safety and to develop a comprehensive program of maintenance, rehabilitation and replacement. Where the deck has a bituminous surfacing, detecting deterioration in the concrete slab presents serious technical difficulties. In many cases, existing procedures are not adequate to produce reliable information.

This study reports the technical and economic evaluation of the following test techniques: chain drag, sonic reflection, ultrasonic transmission, microseismology, resistivity, electrical potential, radar and thermography. All the techniques were investigated under controlled conditions at a full scale test site. The results were compared with the criteria developed for an ideal test method.

Radar and thermography were found to have the most potential for development into routine operational procedures for detecting deterioration in asphalt-covered bridge decks. The additional development work needed was identified.

Introduction

Knowledge of the condition of the bridges within its jurisdiction is essential for a highway agency to ensure a safe and adequate system and to develop a comprehensive program of maintenance, rehabilitation and replacement. In recent years, bridge decks have been especially prone to rapid deterioration wherever deicing salts are use. Though time-consuming, collecting reliable information on the condition of exposed concrete decks is relatively straightforward (1). Determining the condition of asphalt-covered decks presents an entirely different set of problems. Not only can the asphalt hide defects until they are well advanced, it is often difficult to distinguish between deterioration in the concrete deck slab and debonding of the overlay.

The difficulty of collecting reliable information on the condition of asphalt-covered decks is particularly acute in Ontario, where approximately 80% of the bridge decks have a bituminous surfacing and the age of the structures and types of deterioration vary widely. Decks built prior to 1963 were paved with asphalt but were built to lower-quality construction standards than modern structures, without the benefit of efficient waterproofing systems and often with inadequate air entrainment. These structures are prone to scaling of the concrete which is often severe and, in extreme cases, the full depth of the deck slab is affected by freeze-thaw induced damage. Decks built between 1963 and 1972 were constructed with an exposed concrete surface. Many of these decks suffered corrosion of the reinforcement and have subsequently been patched, waterproofed and paved, though in many cases the corrosion activity is continuing (2). Since 1972, decks have included a waterproofing membrane and, more recently epoxy coated bars. These decks are, in general, in good condition although localized deterioration is possible at defects in the membrane.

In addition to the biennial inspection of all structures, detailed condition surveys are carried out on asphalt-covered decks when a structure is located on a section of highway to be repaved, when deterioration is suspected or is known to exist, and the decision must be made whether to repair or replace the structure. Information from condition surveys is also used to establish priorities for repair, select the repair method and prepare contract documents. Existing procedures require a thorough visual inspection supplemented by physical testing which includes a chain drag survey and the measurement of electrical potentials. Cores are taken and tested for chloride content, air-void analysis, strength and, sometimes, a petrographic analysis is made. This testing is expensive: while costs vary with deck size and location, the average is \$10 m^{-2} or about \$5000 for a typical bridge deck. Despite this systematic approach, the information generated is sometimes inadequate for decision making.

The investigation which is reported here was undertaken to identify those procedures having the potential to detect deterioration in asphalt-covered bridge decks more accurately than conventional procedures. While the prime objective of the study was to improve the quality of information, reducing costs would be an important secondary benefit.

Requirements for a Test Procedure

The requirements for the ideal test procedure can be defined as follows:

1. The procedure should be independent of

   a) concrete deck type and thickness;
   b) thickness of bituminous surfacing; and
   c) presence and type of waterproofing.

2. Testing should be required only on the top surface of the deck; it should be non-destructive and preferably non-contact.

3. The test results should not be influenced by climatic conditions, especially temperature and precipitation.

4. The procedure should be rapid, accurate and inexpensive.

5. The results should be quantitative and should preferably be transcribed to a scale plan of the bridge deck using automated equipment.

The extent to which these ideal requirements can be compromised will vary. For example, in urban areas where the costs of traffic control measures for lane closures is high, there is a greater priority for a procedure which can be carried out from a moving vehicle than in low-traffic volume rural areas. Similarly, a procedure which was rapid and accurate but effective only under specific weather conditions would still be useful providing that several bridges could be inspected when the appropriate conditions prevailed.

Candidate Systems

A review of the technology of non-destructive testing was undertaken to identify those techniques which might have application to asphalt-covered bridge decks. Each technique was assessed for its potential to satisfy the criteria developed for the ideal test procedure. A summary of the assessment is given in Table 1. Other techniques such as nuclear radiation and x-rays were considered but were not evaluated, either because they are insensitive to locating fracture planes perpendicular to the direction of the radiation or because the time required for data collection rendered them impractical.

A procedure which is shown in Table 1 to be independent of deck and overlay thickness means that the thickness does not need to be known in order to calculate or interpret the results. This does not imply that the results are not affected by overlay thickness and, in fact, the sensitivity of most methods decreases as the overlay thickness increases. Temperature (above 0°C) has been listed as the only weather variable since none of the test methods would normally be used during precipitation, when free moisture is present on the deck surface or in sub-freezing temperatures.

The Papineau Creek Test Site

Preliminary testing of some of the procedures indicated that the correlation between anomalous areas and the physical condition of the deck slab would be expensive and presented serious logistical problems. It is not practical to remove and replace asphalt on several bridge decks to investigate anomalies in tests results. Attempting to schedule the testing on decks which were part of active rehabilitation contracts also proved unsatisfactory, either because the availability of equipment and manpower did not match the contractor's schedule or the decks did not exhibit deterioration.

The decision was made to create a test site which included the types of deterioration of interest and one where all the test procedures could be evaluated under controlled conditions. The Papineau Creek Bridge, located near Bancroft, Ontario was selected for the test site. The structure, built in 1968, has three spans and consists of a thin slab deck on prestressed concrete beams. It is 36.9 m long and 9.14 m wide between curbs and typical of a large number of bridges in the Province. The bridge was built with an exposed concrete deck surface, and by 1980, the deck exhibited corrosion-induced distress. The condition of the structure was documented, instrumentation installed and a bituminous surfacing was placed without making repairs to the deck slab.

The condition of the existing deck slab was recorded by measurement of the electrical potential and cover of the reinforcing steel on a 0.5 x 0.5 m grid and by plotting delaminated areas and spalls on a site plan. The delaminations were detected using both a chain drag and a hammer. The spalls occupied 0.2% of the deck area and the delaminations 6.4%. The location of the delaminations is shown in Figure 1(a) and were in the form of a large number of small delaminations predominantly associated with the reduced cover present over the two piers. Cover measurements were in the range of 17 to 44 mm with an average of 32 mm. Electrical potentials ranged from -0.07 to -0.58vCSE with 14% of the deck area more negative than -0.35vCSE.

Prior to paving thermocouples were installed at several locations in the deck and on the deck surface. A section of the deck was also selected to simulate the presence of scaling and to introduce lack of bond between the bituminous overlay and the concrete deck slab. The scaling was simulated by placing coarse sand to a thickness of approximately 10 mm at three locations. The debonding was accomplished by attaching circular and triangular masks to the deck at six locations prior to application of an asphalt emulsion tack coat to the entire deck. After the tack coat had cured, the masks were removed and a thin layer of powdered talc spread directly on the concrete surface. The

areas of debonding and scaling are shown in Figure 2. The deck was paved with two 40 mm lifts of bituminous concrete using conventional materials and equipment. Thermocouples were installed at two locations between the two overlay courses.

Evaluation of Test Procedure

Tests were undertaken of the procedures listed in Table 1 to determine their effectiveness and to assess the practicality and economy of the procedures in identifying the known areas of deterioration and debonding at the Papineau Creek Test Site.

i) Chain Drag Survey

Two sonic techniques were investigated, both of which depend upon monitoring the audible sound resulting from striking the deck surface. The chain drag is the traditional method of identifying delamination in exposed concrete bridge decks and has been found effective for this purpose (3,4). Delaminations are detected by the change in frequency of the sound resulting from the impact of a chain on the deck surface. The inspector normally marks the extent of the delaminated area on the deck surface and later notes the size and location on a grid sheet.

The chain drag survey at the test site was performed by a technician experienced in the technique but who had no prior knowledge of the condition of the deck. The results are shown in Figure 1(b). Six areas were identified as delaminated. Five corresponded to known delaminations but the areas were smaller than the actual delaminations. The sixth area corresponded with the largest area of scaling and the technician did indicate the sound was different from the other delaminations but could not explain the difference in terms of physical distress. The five areas of delamination represented 0.5% of the deck area, or 13% of the known delamination. The areas of debonding were not detected.

ii) Sonic Survey

The second sonic technique involved the use of a commercial instrument developed and used for delamination detection on exposed concrete bridge decks (5, 6). It has also been claimed to be capable of detecting delamination up to 115 mm below the surface of asphalt-covered decks (5).

The equipment consists of two tapping devices which operate at a frequency of 34 Hz, a sonic receiver and a two-channel pen recorder mounted on a small

cart. The instrument is pushed along the deck at walking speed and the sonic transducers pick up the sound generated by the tapping devices and reflected through the concrete.

Two surveys were made, one in 1980 and the other in 1981. Since the instrument surveys only a 150 mm wide band on each pass, a grid line spacing of 0.4 m was used to minimize the possibility of missing small, isolated delaminations. This grid line spacing is much less than would be considered normal in commercial practice where grid lines are typically 1.5 m apart.

The calibration procedure used in the first survey was the same as that used on exposed concrete decks. The results, shown in Figure 1(c) indicated that 10% of the deck was delaminated but the correlation with the location of the actual delaminations was poor. The lack of precision was attributed to the calibration procedure, which was considered unsuitable because of the different attenuation characteristics of asphalt and concrete.

In the second survey, the instrument was again calibrated using the standard bar, and then an operator, experienced in work on asphalt-covered decks, adjusted the gain controls to reduce the sensitivity. The results are shown in Figure 1(d) and indicated deterioration in 1% of the deck area, or approximately 16% of the known delamination. The correlation between the location of the deterioration indicated and existing was only fair. The instrument could not distinguish between the scaling and delaminations and did not identify the areas of debonding.

iii) Ultrasonic Transmission

In ultrasonic techniques, high frequency sound waves are introduced into the test material. The sound waves travel through the material at a velocity which, in homogenous materials, is related to the density and elastic constants of the material. In heterogeneous materials such as concrete, the wave velocity is also a function of the composition of the material and its porosity. The sound waves are reflected at interfaces in all materials and this enables discontinuities and flaws to be detected. Ultrasonic techniques have been used to detect defects and as a measure of the strength of concrete for many years (7, 8).

Measurements were made using commercial ultrasonic equipment equipped with transducers operating at a frequency of 50 kHz and 10 pulses per second. A low frequency is necessary to minimize attenuation and scatter losses which result from the heterogeneous nature of concrete. Consequently, frequencies in the range of 20 to 100 Hz are normally used (9).

The instrument was used in the direct transmission mode with the transducers placed on each side of the deck. Glycerine was used to reduce coupling losses. The survey was commenced in the area of simulated scaling.

The pulse velocities through the deck did not correspond with known areas of deterioration and testing was terminated because the equipment was considered impractical for this application. A substantial proportion of the deck underside was inaccessible because of its location over water and the presence of the beams and diaphragms. Calculation of the pulse velocity in the deck depends upon a knowledge of the path length between the transducers. Not only was it not possible to align the transducers directly opposite each other, but variations in the thickness of the deck slab and bituminous surfacing can be expected to change the path length by the order of 10%. This is the same order of magnitude as the differences which would be expected from changes in the quality of the concrete. Ultrasonic measurements are especially sensitive to changes in the thickness of the asphalt because of its very high attenuation characteristics. Velocities in concrete are also known to be moisture dependent (8). It is also worth noting that at the Papineau Creek Bridge, in common with many other bridges, the delaminations were predominantly over the piers where the presence of the diaphragms makes the deck soffit inaccessible.

Indirect transmission, in which both transducers are placed on the deck surface, did not yield meaningful results because of the unknown path length in three different materials, i.e. the bituminous surfacing, the concrete deck slab and the reinforcing steel.

iv) Micro-Seismic Survey

Micro-seismic refraction was investigated in the 1940s as a method of measuring the quality of concrete (10) and in the mid 1960s as a means of detecting deterioration beneath asphalt wearing courses (11), though it has not been used extensively for this purpose. The method measures the time, and hence the velocity, of the propogation of a mechanical disturbance through a medium.

A limited survey was carried out with a 12-channel seismograph commonly used in studies of rock strata. Two ten meter grid lines were investigated, one of which was in an area of sound deck and the other in

an area which included delaminations. A 9 kg hammer was used to strike a metal plate on the deck surface to generate the shock wave. The number of blows and the spacing of the geophones was varied to produce an optimum response.

Typical wave traces for the sound and delaminated areas are shown in Figure 3. The equipment was found to be capable of differentiating between sound and unsound areas of the deck. However, interpretation of the data, even with the assistance of seismic experts, was difficult, and it was not possible to define the location of the discontinuities in order to estimate the area of deterioration. It was concluded that, although the test had potential, it was time-consuming and not as promising as some of the other procedures evaluated. Consequently, further testing was not undertaken.

v) Resistivity Survey

The standard resistivity test method for assessing the integrity of membranes (ASTM D3633) was evaluated for its potential to indicate the quality of the concrete. While the method was considered unlikely to be useful for detecting delamination, it was thought possible that moisture within severely scaled areas might change the resistivity sufficiently to identify these areas.

The test was performed on two occasions. The first time the sponges were placed on the deck surface and the resistivity was measured periodically over 4 h using an alternating current resistance meter. On the second occasion holes were drilled through the bituminous surfacing to the concrete surface and resistance readings were taken instantaneously and after a period of 30 min. The readings were erratic during both tests and there was no correlation between the resistivity and the physical condition of the deck slab. The procedure was deemed to be unsatisfactory from the standpoint of both the value of the results and the time required for its completion.

vi) Electrical Potential

The measurement of half-cell potentials to indicate corrosion activity is well established. When used on an asphalt-covered deck, drilling through the surfacing to ensure contact with the concrete surface is desirable. It is essential when a waterproofing membrane is present.

All the grid points were drilled, the holes filled with wetting solution and the half-cell potentials were measured in accordance with the ASTM C876 test method. The potential measurements were found to be less than those recorded prior to paving and the range of values was -0.37 to + 0.03 v CSE. Positive values and low negative values of potential are usually indicative of dry concrete. However, it is not only the absolute value of potential which is important but the range of values which is important. In this case the range of 0.4 v indicates the existence of well-developed anodic and cathodic areas in the deck slab. The pattern on the isopotential lines for the pre- and post-paving conditions is very similar, as shown in Figure 4, though the absolute values are different and may reflect a change in the moisture content of the deck slab. It may also explain why there appeared to be little change in the area of delaminations in the two years after the deck was paved.

The results of the potential survey on the Papineau Creek Bridge are not typical of experience in Ontario on other asphalt-covered decks where there has been a good correlation between corrosion activity and the values of -0.35 and -0.20 v CSE normally used to indicate the presence and absence of corrosion activity respectively. Even though the correlation with corrosion activity is usually good, it is important to recognize that the measurement of potentials will only indicate areas of corrosion-induced distress. It will not identify the deterioration of the concrete by other mechanisms, nor will it identify areas of debonding.

vii) Radar

The use of low power, high resolution, ground penetrating radar for detecting deterioration in concrete bridge decks was first reported in 1977 (12). Additional work resulted in improvements in the accuracy of the technique (13, 14). The system consists of a monostatic antenna, a control console containing a transmitter and receiver and an oscilloscope. A one nanosecond pulse of low power, radio frequency energy is directed into the bridge deck and the echo is received and displayed on the oscilloscope. A very high frequency is required in order to identify delaminations because the size of the discontinuity perpendicular to the impulse is very small. The equipment was mounted on a handpushed cart and the deck was surveyed at the same grid points as used for all the test methods. The wave forms were recorded by an instant camera and analysed manually.

Figure 5(a) shows a typical radar signal for a sound portion of the deck and Figure 5(b) shows the signal for a section known to be delaminated. The part of the waveform of greatest interest is that corresponding to the upper regions of the concrete deck slab and to the interface between the surfacing and the slab. These regions are indicated in Figure 5 together with the other significant features of the waveform. In areas where the concrete is deteriorated or the character of the interface changes, the amplitude and time of the echo also changes.

The ability to detect the interface between the concrete and the asphalt has the important benefit of being able to measure accurately the thickness of the asphalt surfacing. Thicknesses as large as 250 mm have been found in Ontario on some older decks for which records are incomplete. Such large thicknesses have repercussions on the live load capacity of the bridge, as well as increasing the costs of condition surveys and repair contracts. On newer decks which have a good quality waterproofing membrane, it may be possible to use radar to determine if the concrete slab is sound and, by measuring the asphalt thickness, remove most of the surfacing by cold-planing and replace it without disturbing the waterproofing membrane. Such a procedure would result in a substantial reduction in cost from the present practice of replacing the waterproofing membrane when the adjacent roadway is resurfaced approximately every 15 years.

The radar identified 51% of the grid points located over delaminations and the simulated scaling It did not identify the areas of debonding and the operators also falsely indicated numerous grid points to be delaminated, thereby reducing the overall accuracy to 26%. The results are shown in Figure 1(e). However, further examination of the data indicates that the accuracy can be improved considerably. Many of the false readings were actually located close to delaminated areas and since the radar senses an area of approximately 150 cm^2, the presence of these areas influenced the waveform. Continuous recording of the data rather than measurements at discrete grid points would define the areas of deterioration more precisely.

The system as used was rather crude and the interpretation of the wave traces, although done by the developers of the equipment, was subjective because of their limited experience on bridge decks and the absence of correlations between wave forms and the physical condition of decks. The equipment has the potential for significant improvement by mounting the radar in a vehicle in addition to recording the data continuously on analog magnetic tape for off-line

processing. The test time could then be reduced by using several antennae to collect one lane-width of data and driving the deck at a speed of no more than 20 km/h. Appropriate software could be developed to analyse the data automatically.

The radar system satisfies most of the requirements for the ideal test method. The only environmental influence is the presence of moisture within the surfacing which will affect the wave form.

viii) Thermography

Temperature measurements were made as part of the investigation of the validity of thermography using thermocouples installed in the deck prior to and during paving.

Figure 6 shows a temperature profile through the deck on a summer day with minimal cloud cover. The profile is very similar to that recorded on exposed concrete decks (4). In the early morning the temperatures were sensibly uniform throughout the deck. This represents the transition period as the temperature of the surfacing changes from being cooler than the concrete deck slab during the night to warmer during the day. As the deck began to heat a substantial temperature gradient developed through the deck. By 11:00 h the difference in temperature between the thermocouples at various levels in the deck was well established. There was also a clear difference between the temperatures measured 5 mm below the concrete deck surface in solid and delaminated areas (thermocouples 4 and 5). This difference was also present, though less pronounced, on the thermocouples (15 and 12) located between the two lifts of asphalt directly above thermocouples 4 and 5 and on the deck surface as shown in Figure 6 and Table 2. Surface temperature measurements were made with a contact probe. Since the infrared scanner also measures surface temperature, the temperature measurements explain why thermography is capable of detecting delaminations in the concrete slab. The time and power required for the temperature gradient to develop also explains why artificial sources of heat are not feasible. The difference in surface temperatures over the solid and delaminated sections reached a maximum of 2° at 14:00 h and then gradually diminished until it was only 0.2°at 18:00 h. This pattern is very similar to that reported for exposed concrete decks though the "window" during which thermography can be used to detect delamination is much smaller on asphalt-covered decks.

Several commercial infrared systems were tested using various configurations of the equipment. The systems were tested at ground level from a boom truck and, in some cases, from a helicopter.

Airborne testing was found to be beyond the capability of even the most sensitive equipment since both the spatial and thermal resolution is inadequate to recognize delaminations from the minimum altitude required by air regulations. The viewing angle at ground level was found to be too flat and the field of view too small. Delaminations were visible but poorly defined and there was interference from radiation reflected from the deck surface. The boom truck was found to be the most practical platform from the point of view of both accuracy and speed. The optimum height above the deck for the camera was in the range 4 to 6 m to give the best definition of delaminated areas with the least interference from reflected radiation. Spatial resolution was good and changes in surface emissivity caused by tire marks and oil spills could be identified and were not confused with delaminations.

Figure 7 enables a comparison to be made in three areas between thermograms taken from the boom and the delaminations which were present in the deck prior to paving. The delaminations are visible as white or hot areas against a dark or cooler background. The correlation with the pre-paving condition of the deck slab was excellent, though the outline of the delaminations was less distinct or "softer" as a result of dissipation of heat in the bituminous surfacing. The delaminations first became visible at 11:30 h, the definition improved until about 15:00 h when the thermograms illustrated in Figure 7 were taken. The resolution then deteriorated until by 18:00 h the delaminations were barely visible. These observations are consistent with the data contained in Table 2. The scanner detected more than 90% of the known delaminations, some of which were less than 150 mm diameter. The areas of scaling and debonding were not visible in the thermal images. Debonding was not detected because the bituminous surfacing and the deck slab were in intimate contact and did not cause a thermal discontinuity. The inability to detect the scaling was ascribed to the fact the areas were located adjacent to the curbs and any difference in surface temperature was masked by flares on the image resulting from the difference in emissivity between the asphalt deck surface and the concrete curbs. Of the commercial systems which were used, only those which had a full gray scale setting of two isotherm units and a minimum thermal resolution of 0.2°C were found capable of detecting the delaminations.

A potential problem with the use of thermography is that, while a positive result is valid, a negative result may mean that the deck is free from delaminations or that the deck contains delaminations but these could not be detected under the weather conditions prevailing at the time of test. As already noted, differences in surface temperature develop more slowly on asphalt-covered decks than exposed concrete decks and are more sensitive to weather conditions. It was found that a period of early morning heating, during which the cloud cover was less than 40%, was essential to the development of differences in surface temperature. Thermography was successful in identifying the delaminations on days when the air temperature was not less than 18°C, the wind no greater than 40 km/h and the relative humidity was less than 50%. Under these conditions, delaminations were never visible before 10:00 h but could be identified during the period 11:30 to 18:00 h. While further testing and experience will better define the conditions under which thermography is applicable, the above parameters constitute a useful practical guide. Methods of predicting the temperature distribution in bridge decks from a knowledge of atmosphere data, member sizes and the properties of the deck materials have been developed (15, 16). It is possible that analytical studies may assist in defining the conditions under which the necessary differences in surface temperature will develop.

Coring Program

After evaluation of the different test procedures, cores were taken at selected locations to confirm the existence of defects and to investigate the reason for anomalies identified by some of the test methods. The results are given in Table 3 and the condition of the cores taken at four of the grid points is illustrated in Figure 8.

The cores confirmed the existence of the delamination and scaling known to be present in the deck and the fact that the surfacing was well bonded to the deck except where bond was deliberately prevented. No new areas of delamination were identified, even where some of the test methods indicated deterioration. Deterioration indicated by the chain drag and thermography was confirmed. In all but one of the cores taken in areas indicated as deteriorated by radar, but where no deterioration was present, the anomaly was the result of steel reinforcement at the grid location. Further experience in interpretation of the signal and the continuous recording of data should enable this condition to be recognized. Concrete, and especially reinforced concrete, is a difficult material to analyze because, being heterogeneous, several dielectrics exist and separate waveforms may be reflected in sound material.

Discussion

A summary of the evaluation of each test procedure is given in Table 4 which also indicates the additional work which is needed to develop some of the methods into practical investigative procedures. An estimate of the cost of each of the procedures not rejected in Table 4 is given in Table 5. While costs will vary with local conditions, the estimates are sufficiently accurate for comparative purposes. Where a service was purchased to include manpower and data analysis, only the total cost is given.

The chain drag and the measurement of electrical potentials did not give sufficient information to be used as a single test procedure. They were, however, found to be useful components of the conventional approach to condition surveys which includes detailed visual inspections and selective removal of the bituminous surfacing and coring. The chain drag has the advantages that the procedure is simple and inexpensive and is useful in identifying anomalous areas for further investigation.

A more precise calibration procedure is required for the sonic reflection device since the capability of the instrument to detect deterioration must be improved significantly for it to have application to asphalt-covered decks. The ultrasonic and resistivity surveys did not yield meaningful results. The microseismic survey was successful in showing differences between sound and delaminated concrete but the procedure was slow, data analysis tedious and qualitative, and microseismology appeared to be less likely to result in a routine operational procedure then either radar or thermography.

Radar most nearly satisfies the criteria for the ideal test method and the technology exists or is being developed to overcome the deficiences noted in this investigation. The principal requirements are to automate the data analysis and to improve the correlation of the signal with the physical condition of deck slab to eliminate false results. It is also anticipated that with more experience and an automated system, the cost of using radar would be reduced substantially if used in routine production work.

Thermography produced the best correlation with the known deterioration at the Papineau Creek Test Site and was also one of the quickest and least expensive test methods. It is recognized that the information produced is not the same as that produced by a conventional condition survey and that physical testing of the concrete in the deck slab will be necessary in some cases. However, the method does have considerable potential for assessing the condition of a large number of asphalt-covered decks in a short time. This information would be adequate for determining whether deterioration is present and for establishing priorities for repair. When used in this manner, the dependence on weather conditions would become less restrictive since several structures could be investigated on days when weather conditions were suitable.

Conclusions

1. Of the several systems which were investigated, radar and thermography have the greatest potential for development into routine operational procedures for detecting deterioration in asphalt-covered bridge decks. Both methods are better suited to the rapid assessment of the overall condition of a large number of decks than to defining exact areas of concrete deterioration for contract purposes.

2. Radar requires further development to automate the data collection and analysis and to improve the interpretation of the signals.

3. Thermography requires better definition of the weather conditions for its use and the development of software to produce a scaled hard copy from videotape.

References

(1) "Durability of Concrete Bridge Decks," NCHRP Synthesis of Highway Practice 57, Transportation Research Board (1979).

(2) Manning, D. G. and Ryell, J., "Decision Criteria for the Rehabilitation of Concrete Bridge Decks," TRR No. 762 (1981), pp. 1 - 9.

(3) Van Daveer, Jonathan R., "Techniques for Evaluating Reinforced Concrete Bridge Decks," ACI Journal, Proceedings, V. 72, No. 12 (1975), pp. 697 - 703.

(4) Manning, D. G. and Holt, F.B., "Detecting Delamination in Concrete Bridge Decks," Concrete International, Nov. 1980, pp. 34 - 41.

(5) Moore, William M., Swift, Gilbert, and Milberger, Lionel J., "An Instrument for Detecting Delamination in Concrete Bridge Decks," HRR No. 451, Transportation Research Board (1973) pp. 44 - 52.

(6) Moore, William M., "Detection of Bridge Deck Deterioration," HRR No. 451, Transportation Research Board (1973), pp. 53 - 61.

(7) Whitehurst, E. A., "Pulse-Velocity Techniques and Equipment for Testing Concrete," Highway Resarch Board, Proceedings V. 33 (1954), pp. 226 - 242.

(8) Malhotra, V. M., "Testing Hardened Concrete: Nondestructive Methods," American Concrete Institute Monograph No. 9 (1976).

(9) Swift, G. and Moore, W. M., "Investigation of Applicability of Acoustic Pulse Velocity Measurements to Evaluation of Quality of Concrete in Bridge Decks," HRR No. 378, Transportation Research Board (1972) pp. 29 - 39.

(10) Long, B. G. and Kurtz, H. J., "Effect of Curing Methods Upon the Durability of Concrete as Measured by Changes in the Dynamic Modulus of Elasticity," ASTM Proceedings, V. 43, (1943) pp. 1051 - 1065.

(11) Phelps, J. M. and Cantor, T. R., "Detection of Concrete Deterioration Under Asphalt Overlays by Microseismic Refraction," HRR No. 146, Transportation Research Board (1966) pp. 34 - 49.

(12) Cantor, T.R. and Kneeter, C.P., "Radar and Acoustic Emission Applied to the Study of Bridge Decks, Suspension Cables and a Masonry Tunnel," Report No. 77-13, Port Authority of New York and New Jersey (1977).

(13) Alongi, A.V., Cantor, T.R., Kneeter, C.P. and Alongi, A. Jr., "Concrete Evaluation by Radar - Theoretical Analysis," Paper presented at the 61st Annual Meeting of the Transportation Research Board, Washington, D.C. (1982).

(14) Cantor, T.R. and Kneeter, C.P., "Radar as Applied to the Evaluation of Bridge Decks," Paper presented at the 61st Annual Meeting of the Transportation Research Board, Washington, D.C. (1982).

(15) Emerson, Mary, "The Calculation of the Distribution of Temperature in Bridges," Report No. LR 561, Transport and Road Research Laboratory, England (1973).

(16) Hirst, M. J. S., "Thermal Loading of Concrete Bridges," Proceedings, International Conference on Short and Medium Span Bridges, Canadian Society for Civil Engineering (1982) pp. 115 - 124.

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TABLE 1: SCREENING OF CANDIDATE SYSTEMS

Test Procedure	Independent of Slab Thickness	Overlay Thickness	Waterproof Membrane	Temperature (above 0°C)	Surface Only	Non-Destructive	Non-Contact	Speed
Chain Drag	Yes	Yes	Yes	Yes	Yes	Yes	No	Slow
Sonic Reflection	Yes	Yes	Yes	Yes	Yes	Yes	No	Moderate
Ultrasonic Transmission	No	No	No	Yes	No*	Yes	No	Slow
Micro-seismic Refraction	No	No	No	Yes	Yes	Yes	No	Slow
Resistivity	Yes	Yes	No	Yes	Yes	No**	No	Slow
Electrical Potential	Yes	Yes	No	Above 10°C	Yes	No**	No	Slow
Radar	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Moderate
Thermography	Yes	Yes	Yes	No	Yes	Yes	Yes	Fast

* Yes if indirect transmission mode used
** Holes are normally drilled through bituminous surfacing

TABLE 2 - TEMPERATURE DATA

Time of Day	Temperature °C					
	5 mm Below Concrete Surface		Between Courses of Asphalt		On Deck Surface	
	Delaminated	Solid	Delaminated	Solid	Delaminated	Solid
0900	26.3	26.2	26.4	26.2	28.9	28.9
1000	28.1	28.0	28.2	28.1	31.9	31.8
1100	33.1	29.4	33.3	33.3	35.8	35.0
1200	34.8	31.1	35.8	35.0	38.4	36.8
1300	37.3	34.5	37.8	37.5	40.5	37.9
1400	39.2	36.1	40.1	39.4	41.5	38.6
1500	40.2	38.1	41.1	40.3	41.7	39.7
1600	40.5	38.5	41.6	40.6	41.9	39.9
1700	39.9	39.2	41.0	40.0	41.6	39.3
1800	38.5	38.5	39.7	38.5	39.4	39.2

TABLE 3 - CORE RESULTS

Core Location	Test Method Indicating Deterioriation	Core Condition
B27.5	Sonic, Chain Drag, Radar	Scaled area 10 mm sand on deck surface
F36	Sonic, Radar	No defects
H9	Sonic, Radar	No defects, Steel present
H11.5	Chain Drag, Thermography	Concrete delaminated
I31.5	Radar*, Thermography	Concrete delaminated
I32.5	None (to verify debonded area)	No bond
J20	Sonic, Radar*	No defects, steel present
K34	Radar*	No defects, steel present
L5	Sonic, Radar**	No bond
L36	Radar*	No defects, steel present
M34.5	Chain Drag, Thermography	Concrete delaminated at two horizons
R10	Radar*	No defects, steel present

* Deterioration indicated in top one-third of concrete
** Deterioration indicated at asphalt/concrete interface

TABLE 4 - SUMMARY OF EVALUATION OF PROCEDURES

TEST PROCEDURE	SUMMARY OF EVALUTION	FURTHER WORK NEEDED
Chain Drag	Identified 13% of delaminated areas. No false results. Independent of weather and inexpensive. Useful screening device when conventional inspection procedures are used.	
Sonic Reflection	Very low accuracy	Develop calibration procedure for asphalt-covered decks.
Ultrasonic Transmission	Impractical	
Micro-seismic Refraction	Identified anomalies but interpretation difficult. Procedure is slow.	Optimize and automate data collection and analysis. Even with improvement, unlikely to outperform radar and thermography.
Resistivity	Results not meaningful	
Electrical Potential	Useful indication of corrosion activity. Does not identify other forms of deterioration.	
Radar	Good correlation with known deterioration but also many false results. Most nearly satisfies the criteria for the ideal test method.	Mount in a vehicle and record data continuously Improve interpretation of data and automate.
Thermography	Excellent correlation with deterioration with no false results. Main disadvantage is dependence on weather.	Record data on video tape and develop software to permit hard copy of scaled image. Define weather conditions for use.

TABLE 5 - COST ESTIMATES FOR THE TEST PROCEDURES

Test Procedure	Equipment Cost		Field Time h	Manpower Required No. x h	Traffic Control(1)	Data Analysis $	Total Cost
	Purchase $	Rental $					
Chain Drag	15		4	1x3h(2) 2x1h(3)	300	60	435
Microseismic	26000	3900/ month	8	1x8h(4)	500	400	1295
Sonic Reflection		650	2	Inc.	200	Inc.	850
Electrical Potential	400(5)		6(6)	2x6h(2)	400	60	640
Radar	37000	2000/ bridge	2(7)	Inc.	200	Inc.	2200
Thermography	30000	2000/ month	1	1x1h(4)	150	200	475
Conventional Condition Survey	∿4000	∿240/ day	8	1x8h(4) 3x8h(2)	500	2200(8)	3500

Notes: Costs are in 1982 Canadian dollars
Deck size assumed to be 300 m^2
(1) Assuming $100 mobilization plus $50/h
(2) At $15/h
(3) To mark out grid lines
(4) At $25/h
(5) Equipment also required for drilling through surfacing
(6) 1 m x 1 m grid
(7) Using magnetic tape for recording data
(8) Includes physical testing of cores

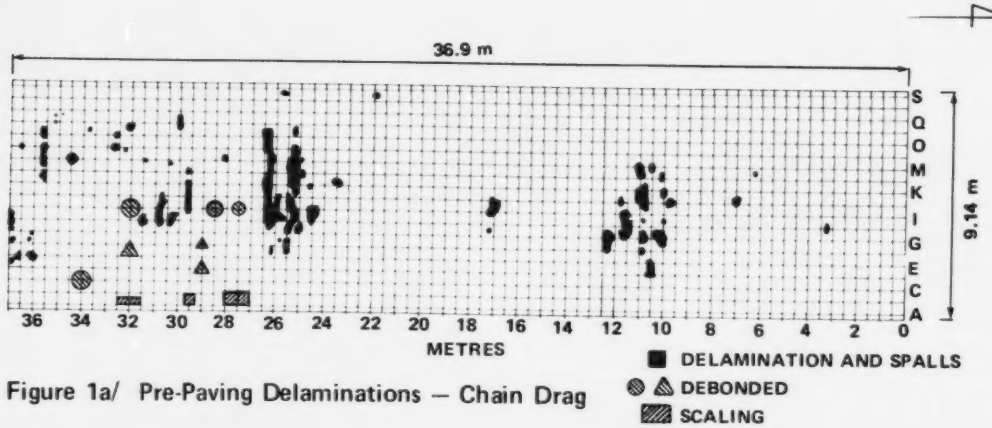


Figure 1a/ Pre-Paving Delaminations — Chain Drag

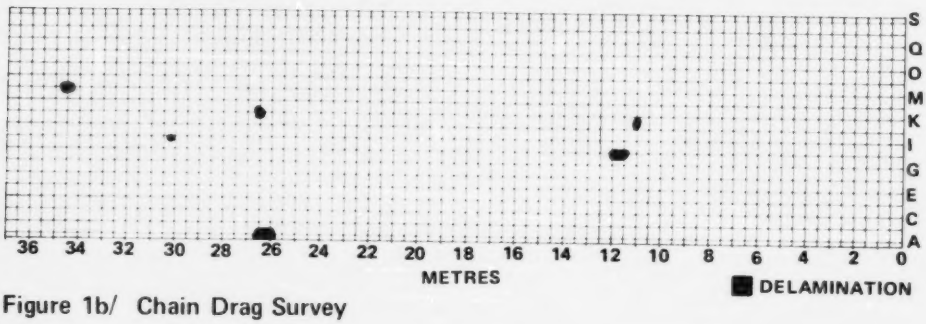


Figure 1b/ Chain Drag Survey

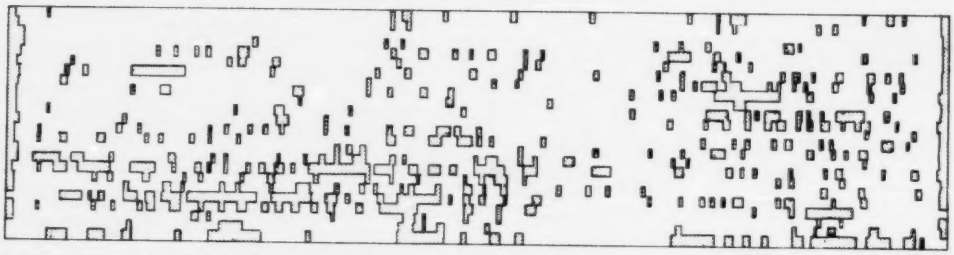


Figure 1c/ Sonic Reflection Survey, August 1980

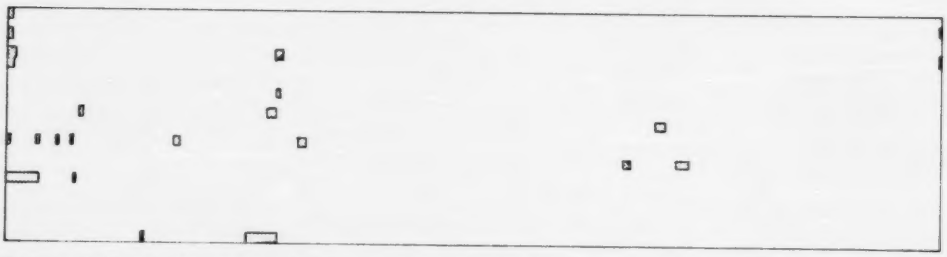


Figure 1d/ Sonic Reflection Survey, June 1981

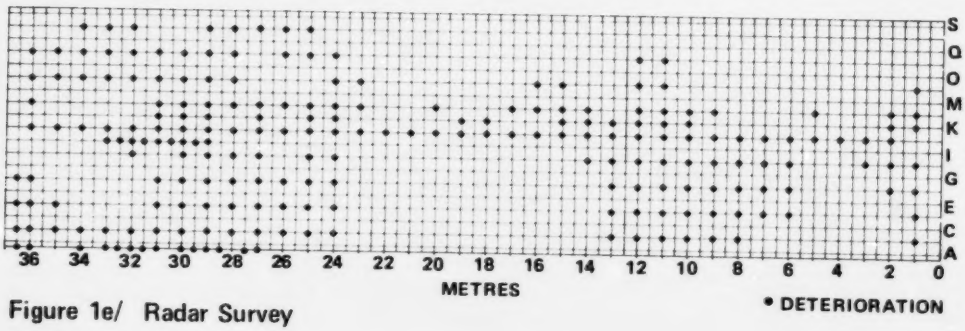
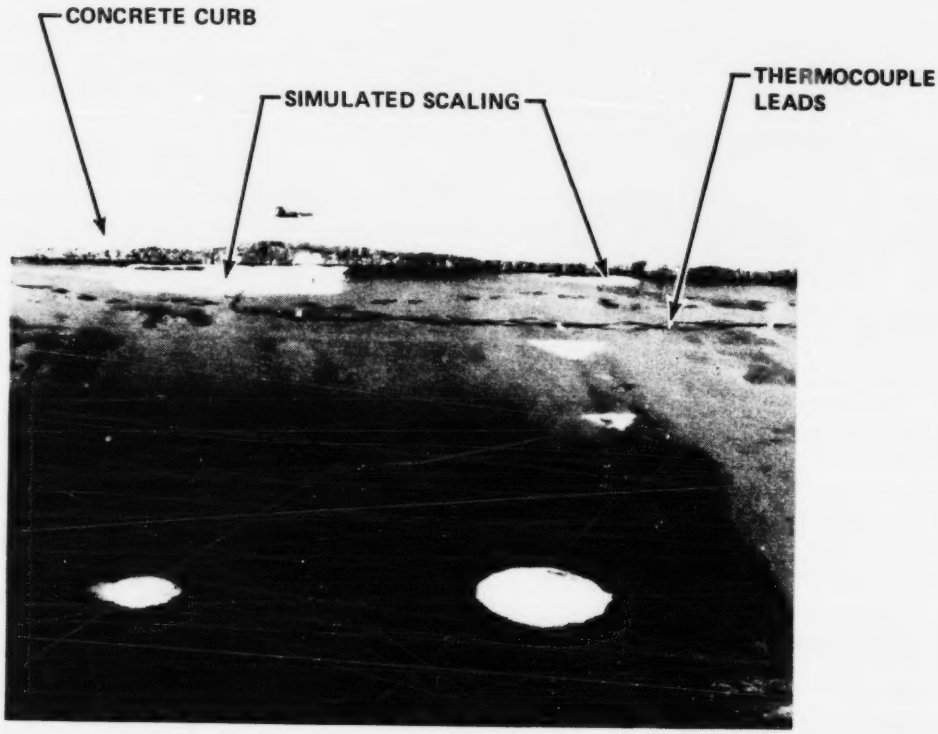


Figure 1e/ Radar Survey



Note: Circles and Triangles are Debonded Areas

Figure 2/ Area of Deck Showing Scaling and Debonding after Tack Coating and before Paving

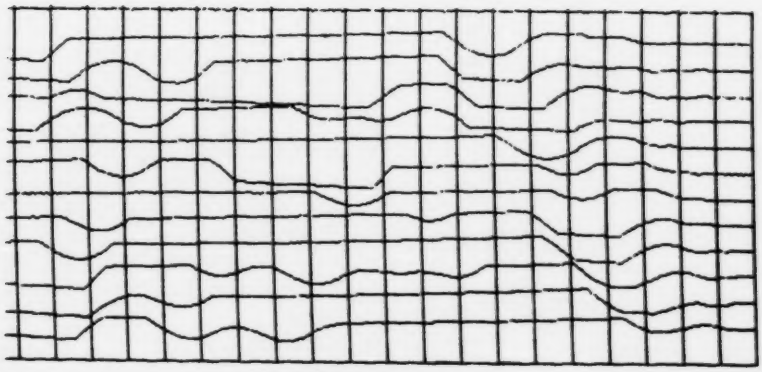


Figure 3a/ Siesmograph Output for Sound Area

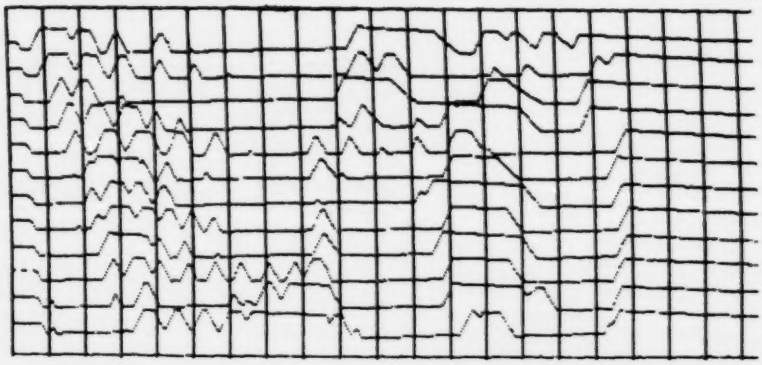


Figure 3b/ Siesmograph Output for Delaminated Area

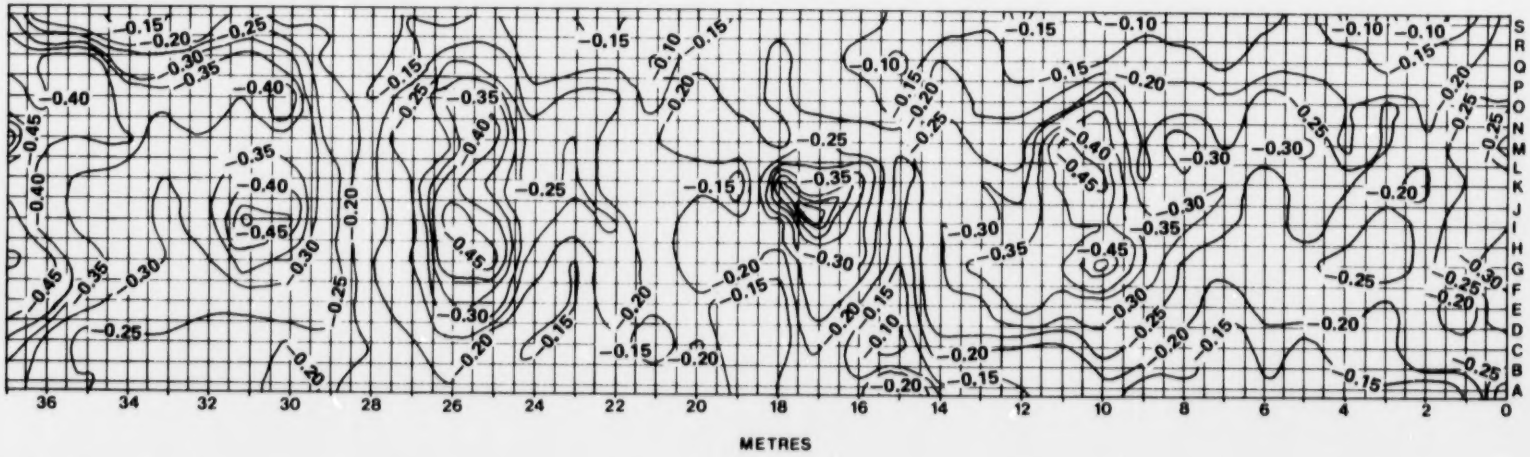


Figure 4a/ Pre-Paving Electrical Potentials

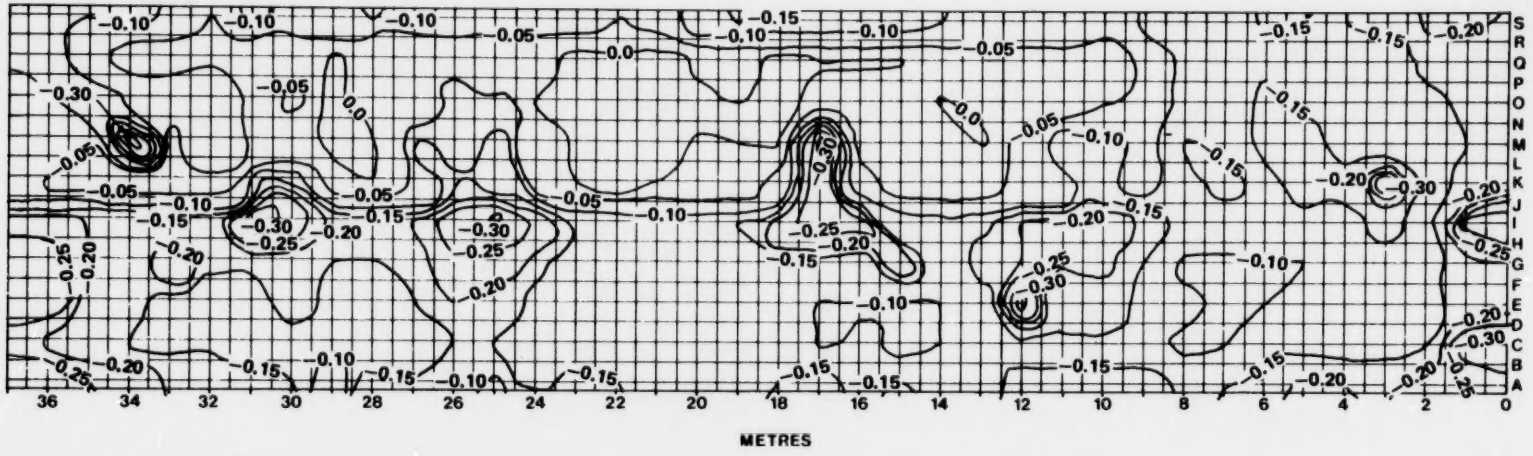


Figure 4b/ Post Paving Electrical Potentials

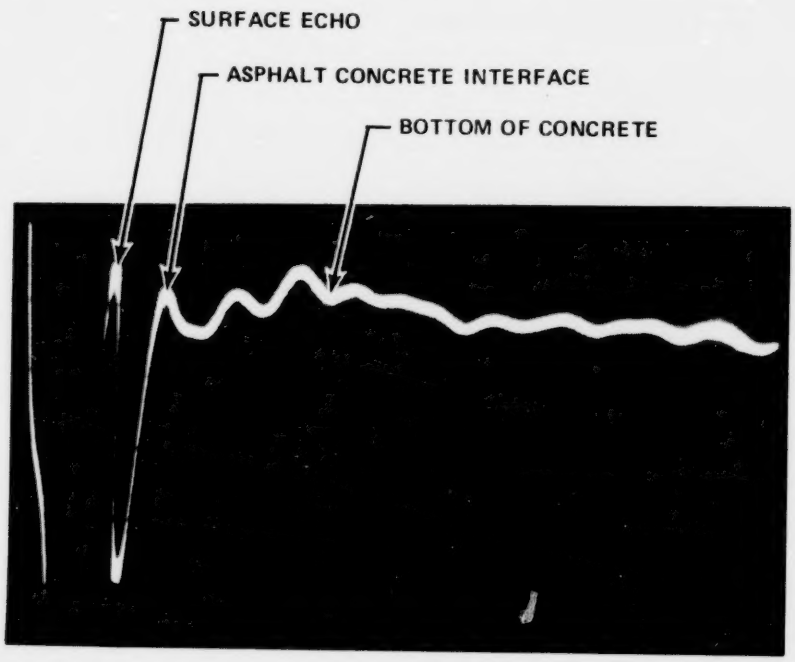


Figure 5a/ Radar Output for Sound Concrete

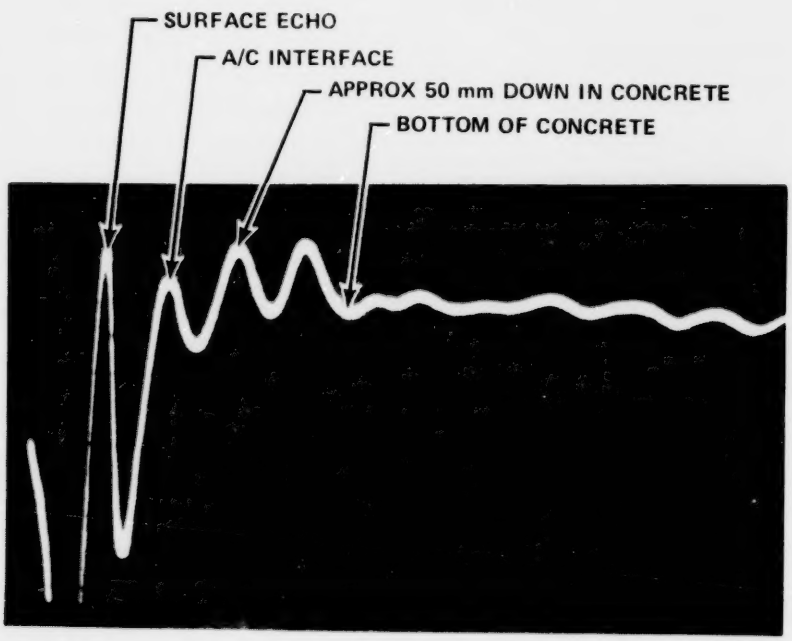


Figure 5b/ Radar Output for Delaminated Concrete

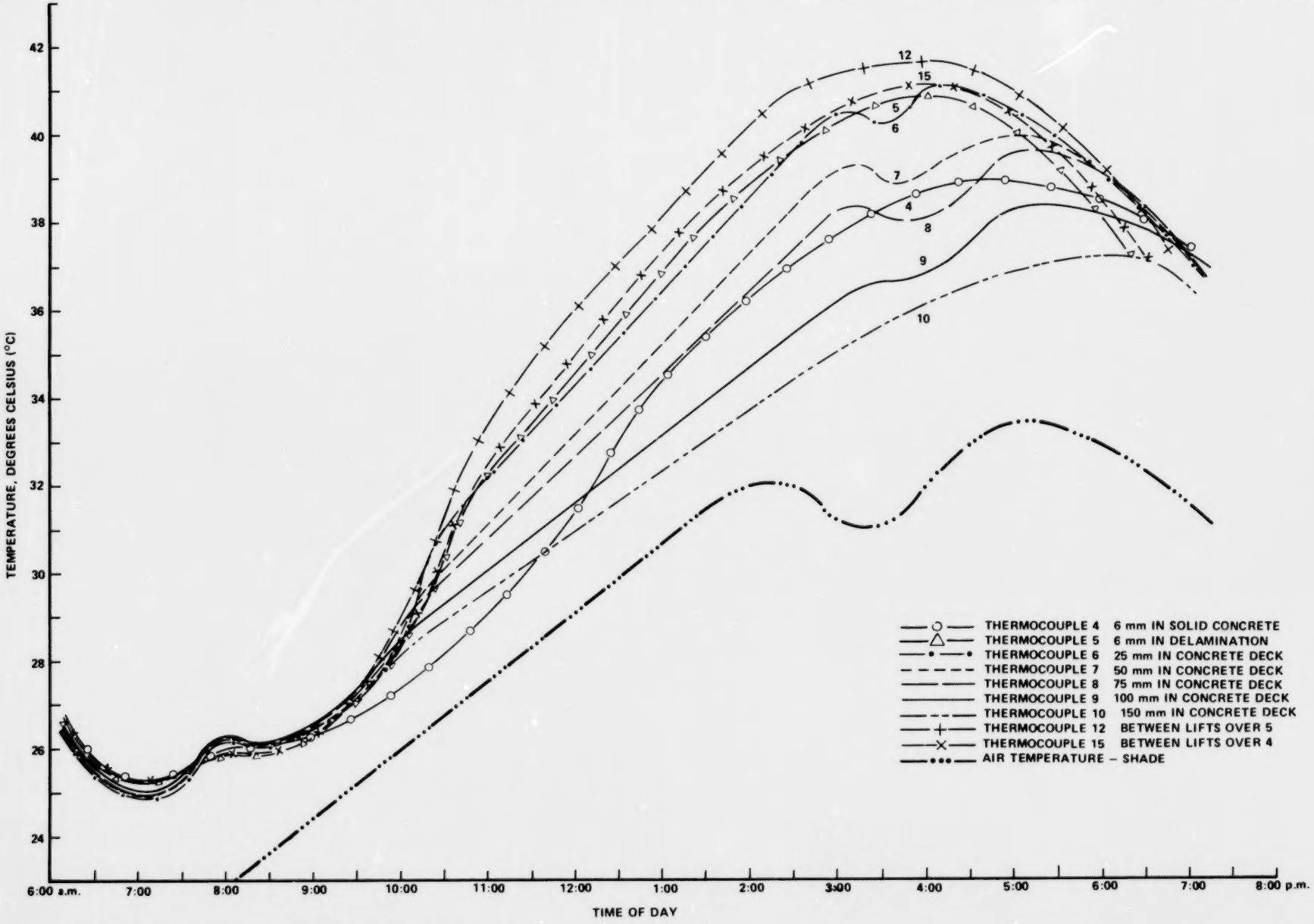


Figure 6/ Temperature Survey Papineau Creek Bridge

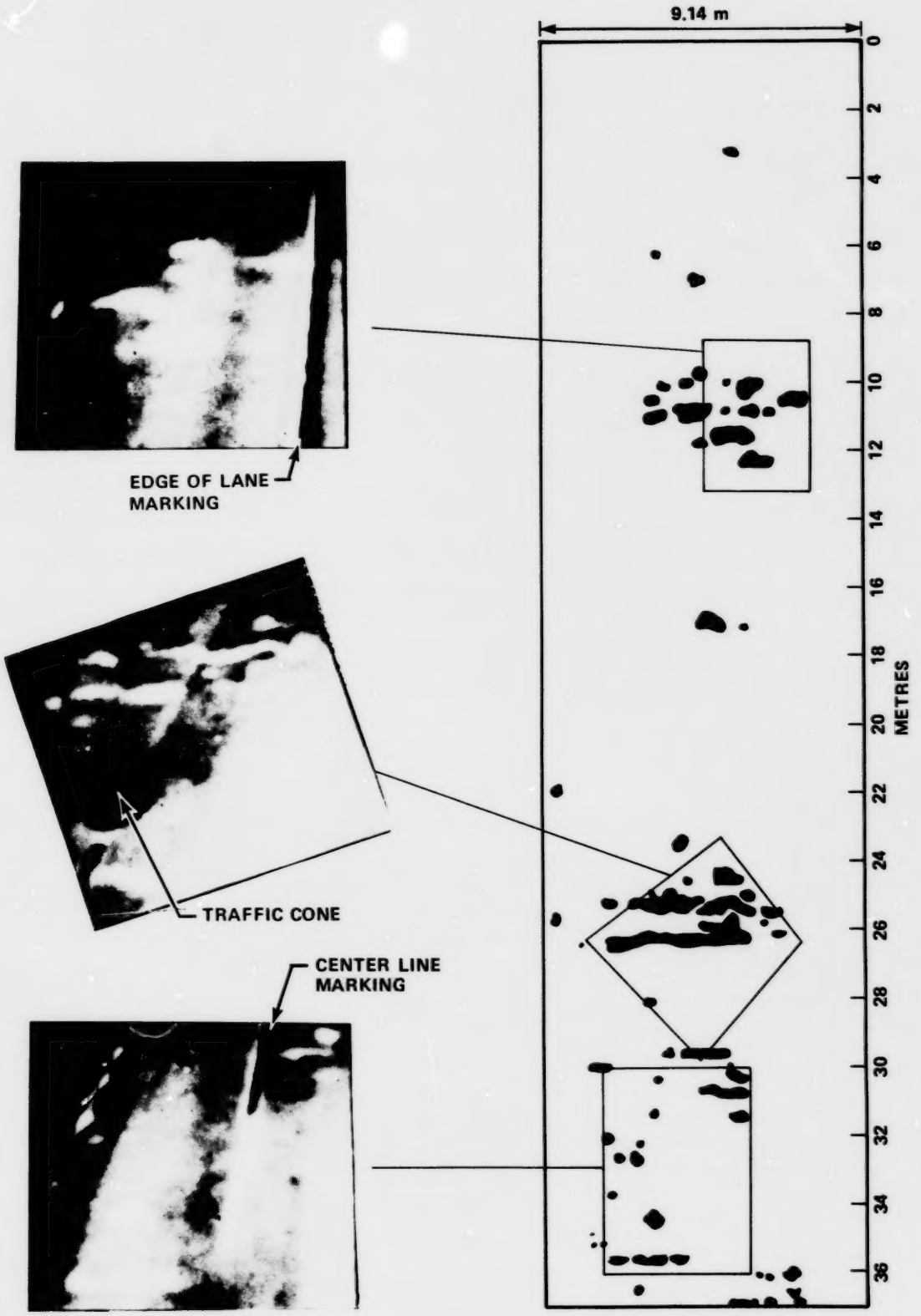


Figure 7/ Thermography Survey

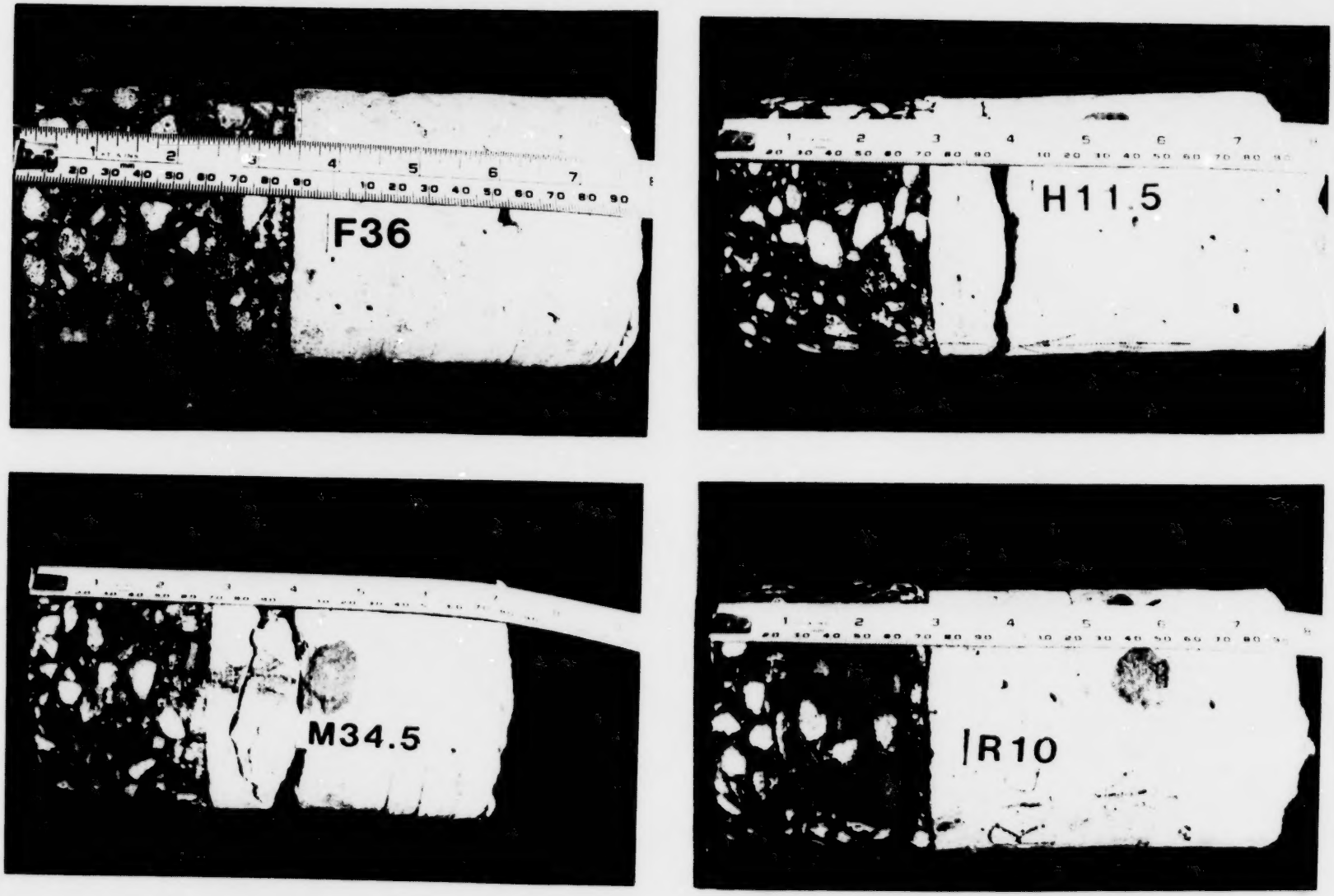


Figure 8/ Condition of Cores Removed from the Deck